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AUTHOR(S): Robert C. Sze
Arthur E. Greene
Charles A. Brau

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Electron Attachment Rates in Cl_2

R. C. Sze, A. E. Greene, and C. A. Brau

Los Alamos Scientific Laboratory
Los Alamos, NM 87545

Our measurement of electron attachment rates in Cl_2 is a continuing effort to obtain quantitative data on all possible halogen donor species that may be relevant to the rare gas halide discharge lasers. In our work to model the lasers and compare them with actual operating devices, it has become evident that the knowledge of attachment rates in the gas mix at very early times during the build up of the voltage is important in properly predicting the voltage and current characteristics of these devices. This requires a knowledge of electron attachment rates at low E/N values and correspondingly low values of mean electron energies. Much of this information is not available in the present literature.

Data are obtained using a small electron beam machine (Fig. 1) which has been described by Brau, Raybun, Dodge, and Gilman.[1] The device utilizes a spiral generator as the high-voltage source and delivers 100 keV electrons through a 25-μm aluminum foil. The current is attenuated through a series of metal screens to values of less than an ampere in an area approximately 6 mm in diameter. Pulse width can be varied from 6 to 20 ns with the fall time for the current at ~ 2 ns.

Attachment rates are obtained by measuring the decay of the current signal when a constant voltage is applied across the electrodes. The separation between the electrodes is 5 mm. A typical decay curve is given in

Fig. 2 for an $E/N = 3.72 \times 10^{-17}$ V-cm^2. Two simultaneous scope traces are obtained so that the data for late times are expanded by a factor of 5. The curves are digitized and a single exponential decay is used to least squares fit the data. In general, data of over an order of magnitude change in signal are used to calculate the time constant for the exponential decay.

Attachment rates are measured in nitrogen and argon mixtures in order to access different regions of mean electron energies. Figure 3 gives data of the attachment rate in nitrogen at a chlorine density of 260 parts per million of the gas mix. The crosses show the attachment data published recently by AVCO.[2] The solid curve is the theoretical calculations using our Boltzman code to obtain the electron energy distribution and it is convoluted with the cross-section data of Kurepa and Belic[3] and Tam and Wong.[4] In the range of E/N where the AVCO data is available both the present data and AVCO's data, as well as the theoretical curve, agree. At the low E/N region the data indicates a rapid rise of the attachment rate that does not agree with the calculations using cross-section data. We will return to this point later in our discussion. The data at each E/N is taken at several pressures of the gas mix.

Figure 4 shows attachment rates as a function of E/N in argon for the same fractional chlorine concentration as in the case of nitrogen. These two sets of data can be plotted together as a function of mean electron energy using the conversion curves shown in Fig. 5. The mean electron energy is obtained for each E/N using the Boltzman code to calculate the electron energy distribution.

The plot of attachment rate as a function of mean electron energy is given in Fig. 6. There are two aspects of this data that are areas of concern. First, is the very steep rise at low electron energies. This rise is certainly also evident from the AVCO data and is not predicted in the calculated curve using the Boltzman code and the cross-section data of Kurepa and Belic. Second, is the peaking of the attachment rate in argon at electron energies lower than that predicted from cross-section data. Since both the cross-section data of Kurepa and Belic and the recent data of Tam and Wong show the $^2\Sigma_u$ peak to be much higher than the $^2\Sigma_g$ peak, (Fig. 7) it seems unlikely that there is a mistake in the relative peak heights in the cross-section data. We feel that the most likely source of error, if there is any, will be in the attachment cross-section value at zero energy. Accordingly, we took the liberty to vary that value in an attempt to fit the argon data. It was necessary to increase the zero energy cross section some two orders of magnitude to a value close to the fluorine cross section, in order to shift the slope to values in agreement with the data. It is, of course, possible that contaminants are giving us these effects in argon and nitrogen, although we feel this to be unlikely. The possibility of HCl contamination can shift the peak in the argon data toward lower energies due to an attachment peak at 1 eV, but would not help to explain the nitrogen data.

The rapid rise of the attachment rate at low electron energies in N_2 is more difficult to explain. One possibility is that rotational excitation was not included in our Boltzman code. We feel, however, that this effect will not become important until E/N goes to value below 10^{-18} V-cm^2. To see if there was some systematic experimental error, we remeasured the attachment rates of fluorine (Fig. 8) measured earlier by Snyder and Brau.[5] The results were in agreement with the earlier values and show no fast rise of the attachment rate at low mean electron energies.

References

(1) C. A. Brau, J. L. Raybun, J. B. Dodge, and F. M. Gilman, Rev. Sci. Insts. 48, 1154 (1977).

(2) M. Rokni, J. H. Jacob, J. A. Mangano, Appl. Phys. Lett. 34, 187 (1979).

(3) M. Kurepa and D. S. Belic, J. Phys. E. (1978).

(4) W. C. Tam and S. F. Wong, J. Chem. Phys. 68, 5626, (1978).

(5) B. I. Schneider and C. A. Brau, Appl. Phys. Lett., 33, 569 (1978).

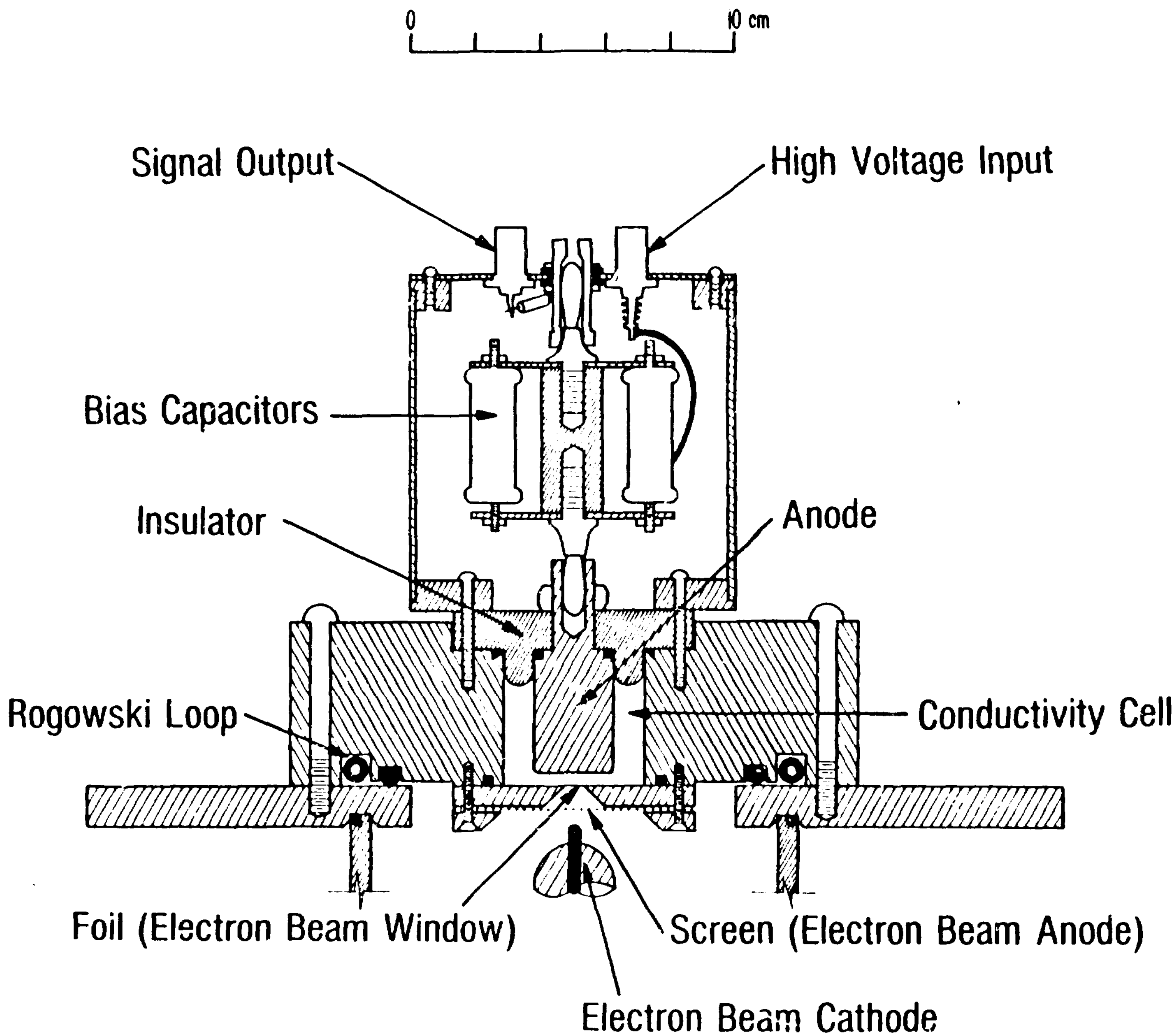
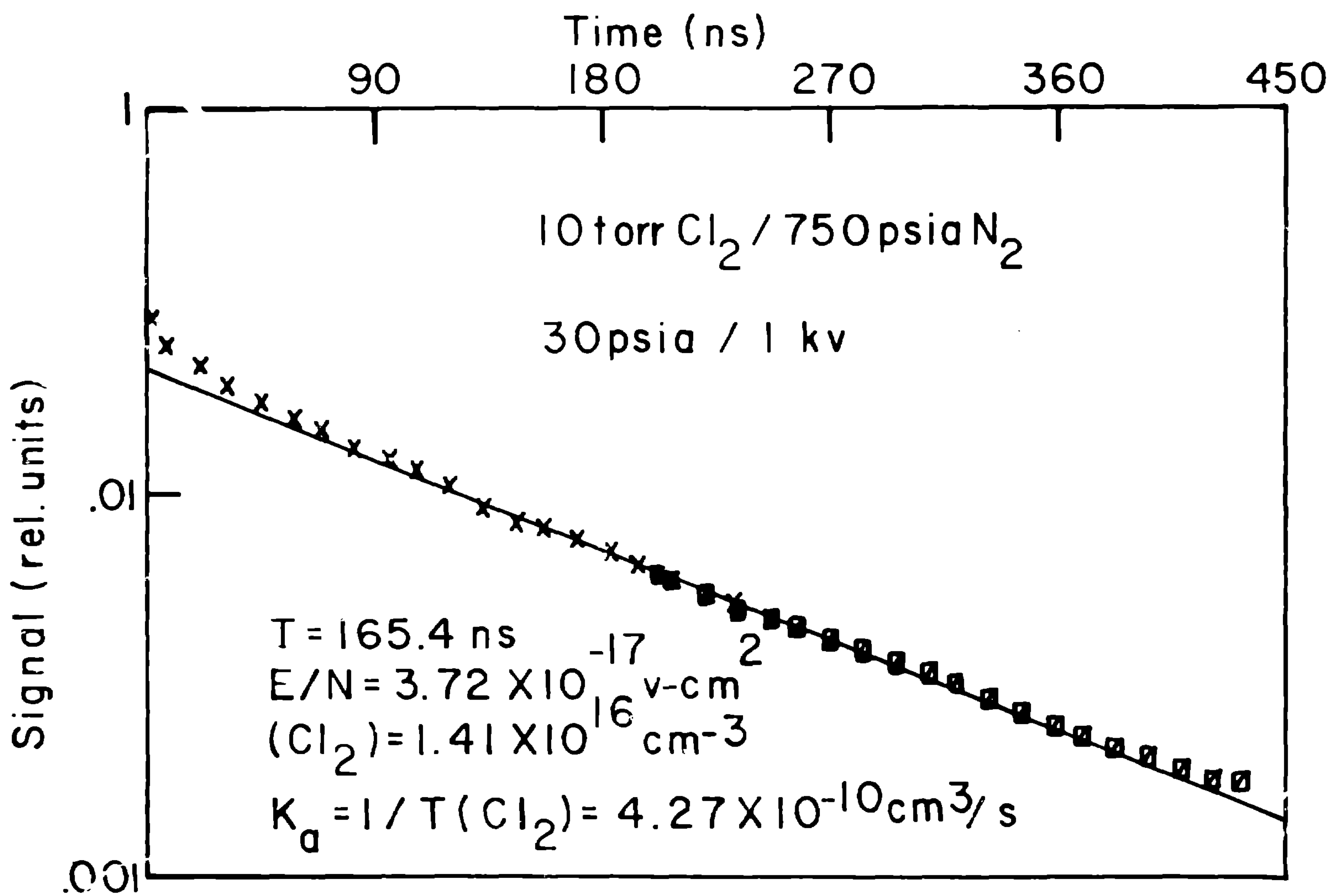

0
10 cm
Signal Output
High Voltage Input
Bias Capacitors
Insulator
Anode
Rogowski Loop
Conductivity Cell
Foil (Electron Beam Window)
Screen (Electron Beam Anode)
Electron Beam Cathode

Figure 1



Time (ns)
90
180
270
360
450
1
.01
.001
Signal (rel. units)
10 torr Cl2 / 750 psia N2
30 psia / 1 kv
T = 165.4 ns
E/N = 3.72 X 10-17 v-cm2
(Cl2) = 1.41 X 1016 cm-3
Ka = 1 / T (Cl2) = 4.27 X 10-10 cm3/s

Figure 2

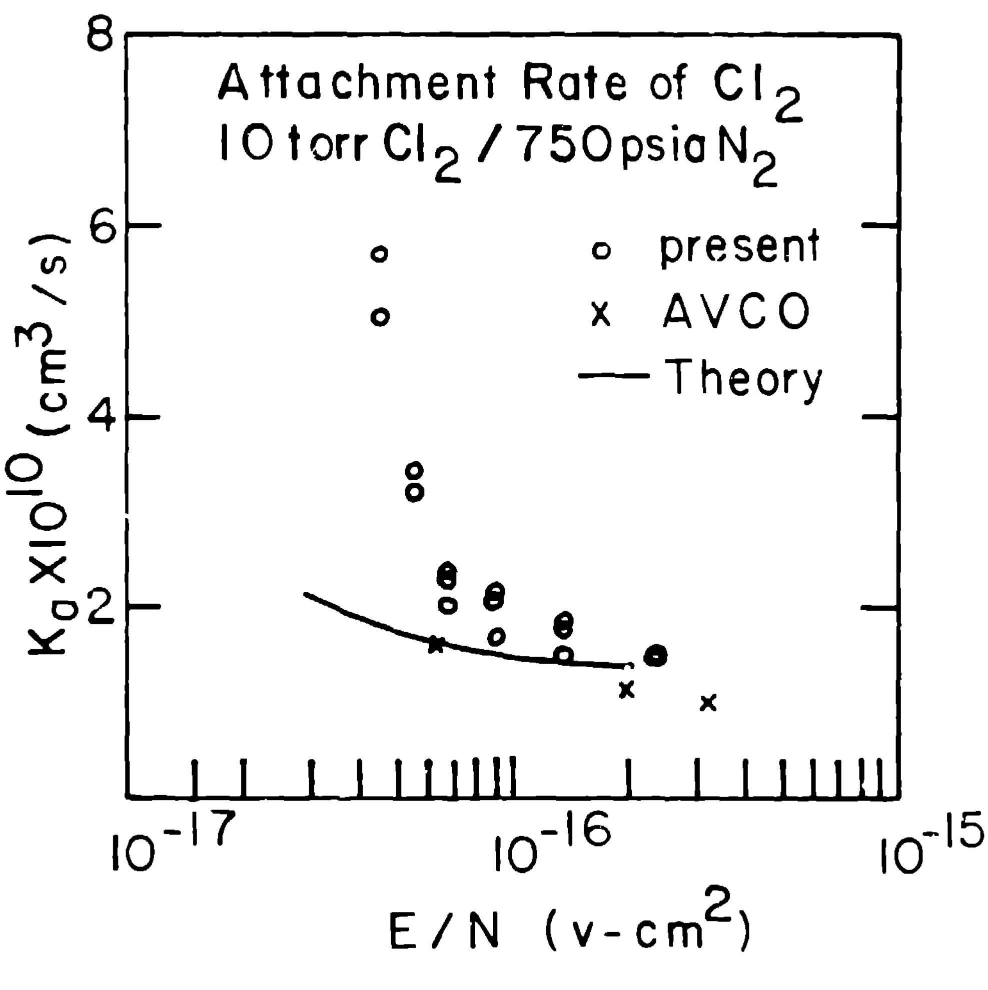
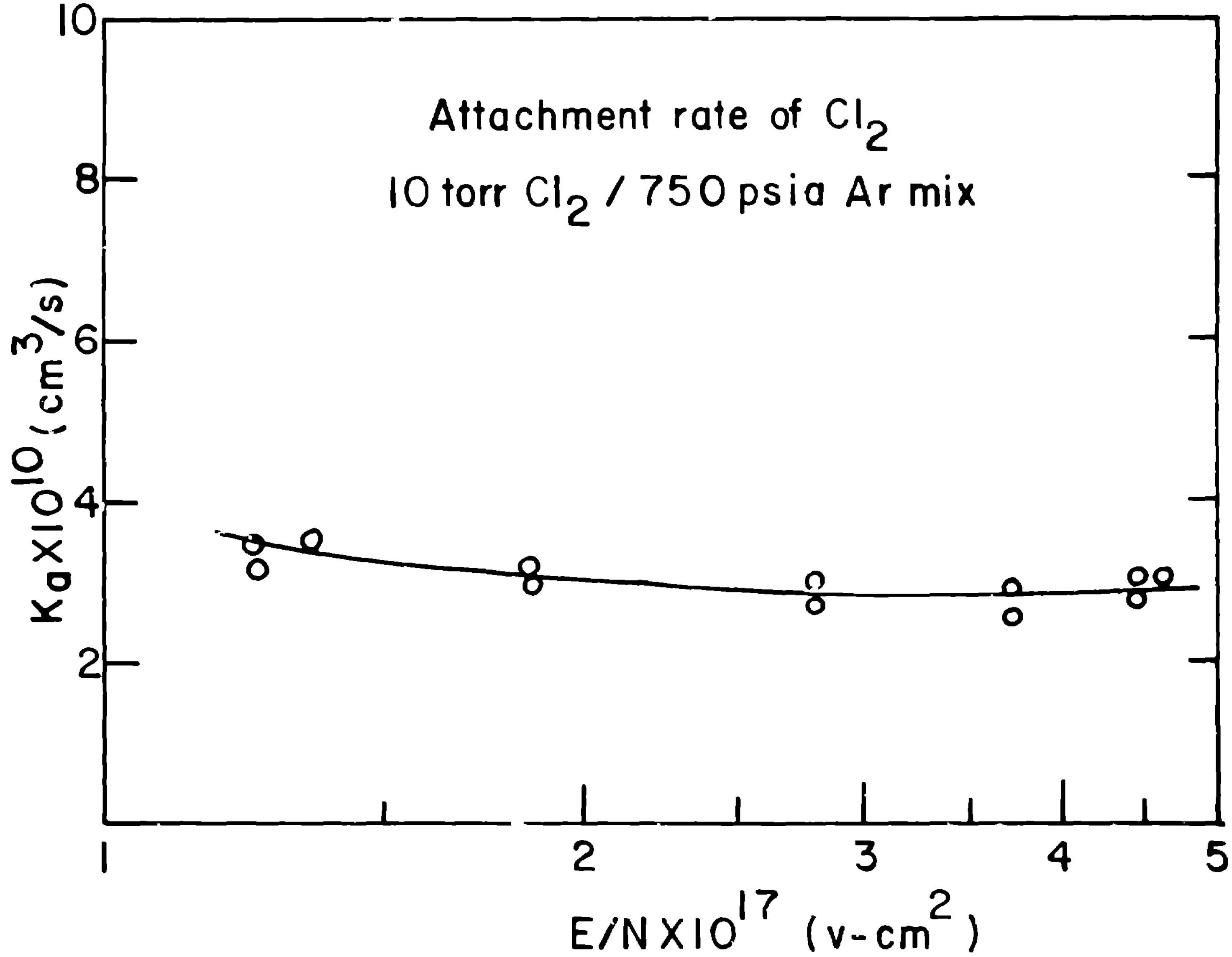
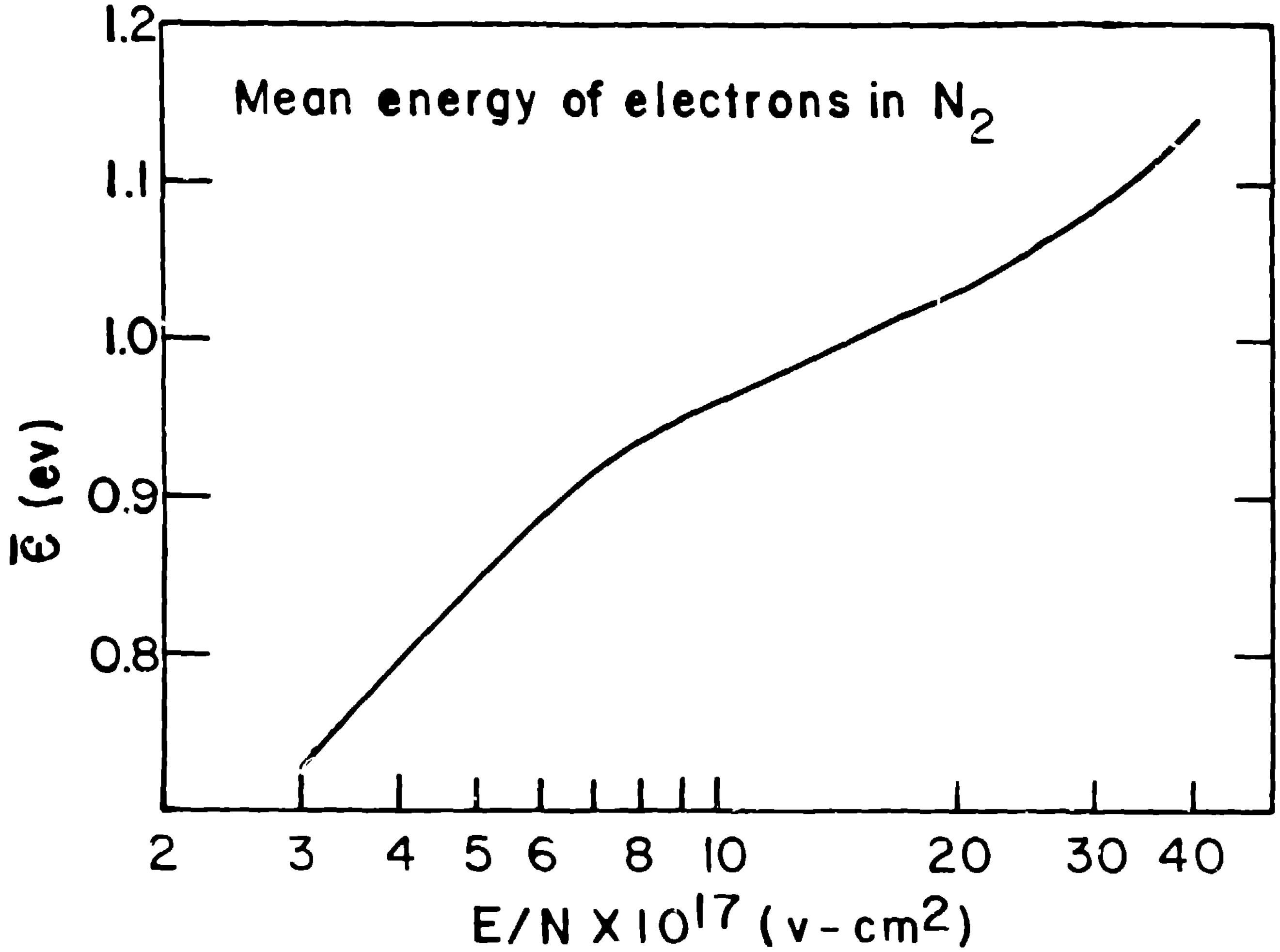

Attachment Rate of Cl2
10 torr Cl2 / 750 psia N2
o present
x AVCO
— Theory
8
6
4
2
Ka X10^10 (cm^3/s)
10^-17
10^-16
10^-15
E/N (v-cm^2)

Figure 3

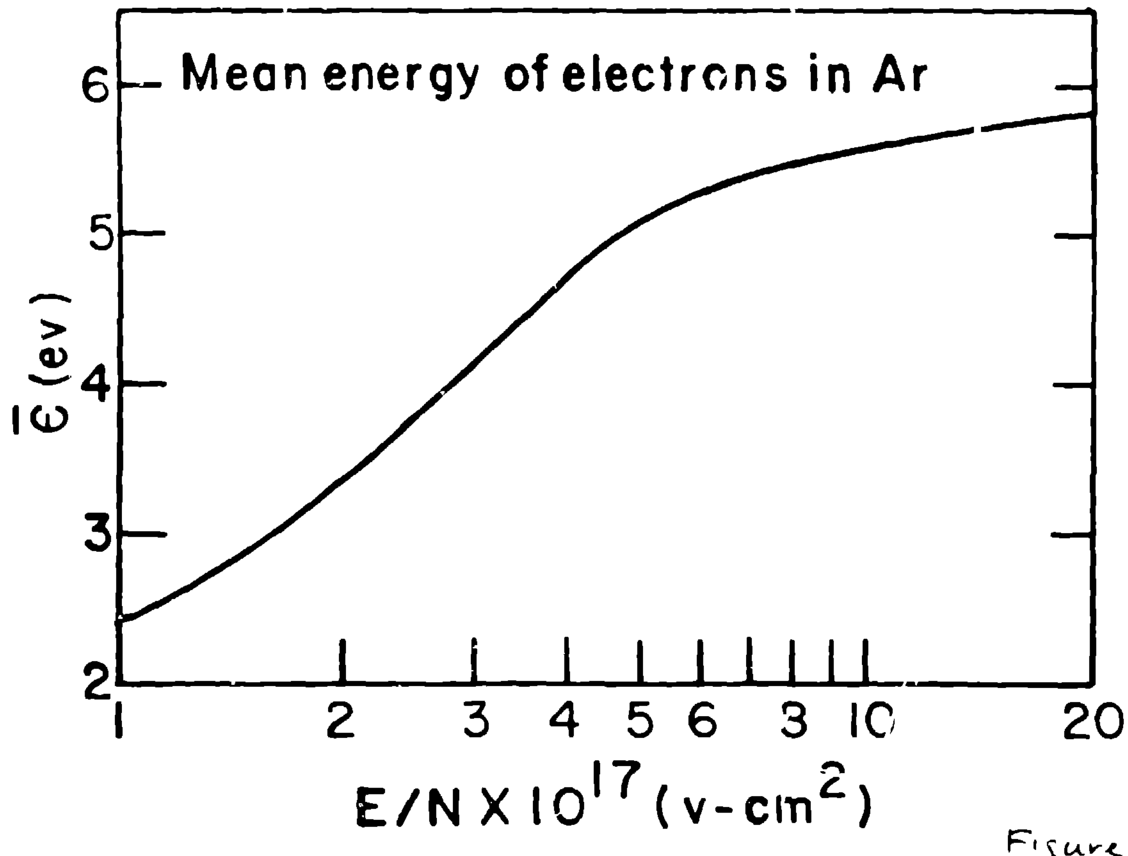


Attachment rate of Cl_2
10 torr Cl_2 / 750 psia Ar mix
$K_a \times 10^{10}$ (cm^3/s)
10
8
6
4
2
1
2
3
4
5
$E/N \times 10^{17}$ (v-cm^2)

Figure 4



Mean energy of electrons in N_2
1.2
1.1
1.0
0.9
0.8
$\bar{\epsilon}$ (ev)
2
3
4
5
6
8
10
20
30
40
$E/N \times 10^{17}$ (v - cm^2)



Mean energy of electrons in Ar
6
5
4
3
2
$\bar{\epsilon}$ (ev)
1
2
3
4
5
6
3
10
20
$E/N \times 10^{17}$ (v-cm^2)

Figure 5

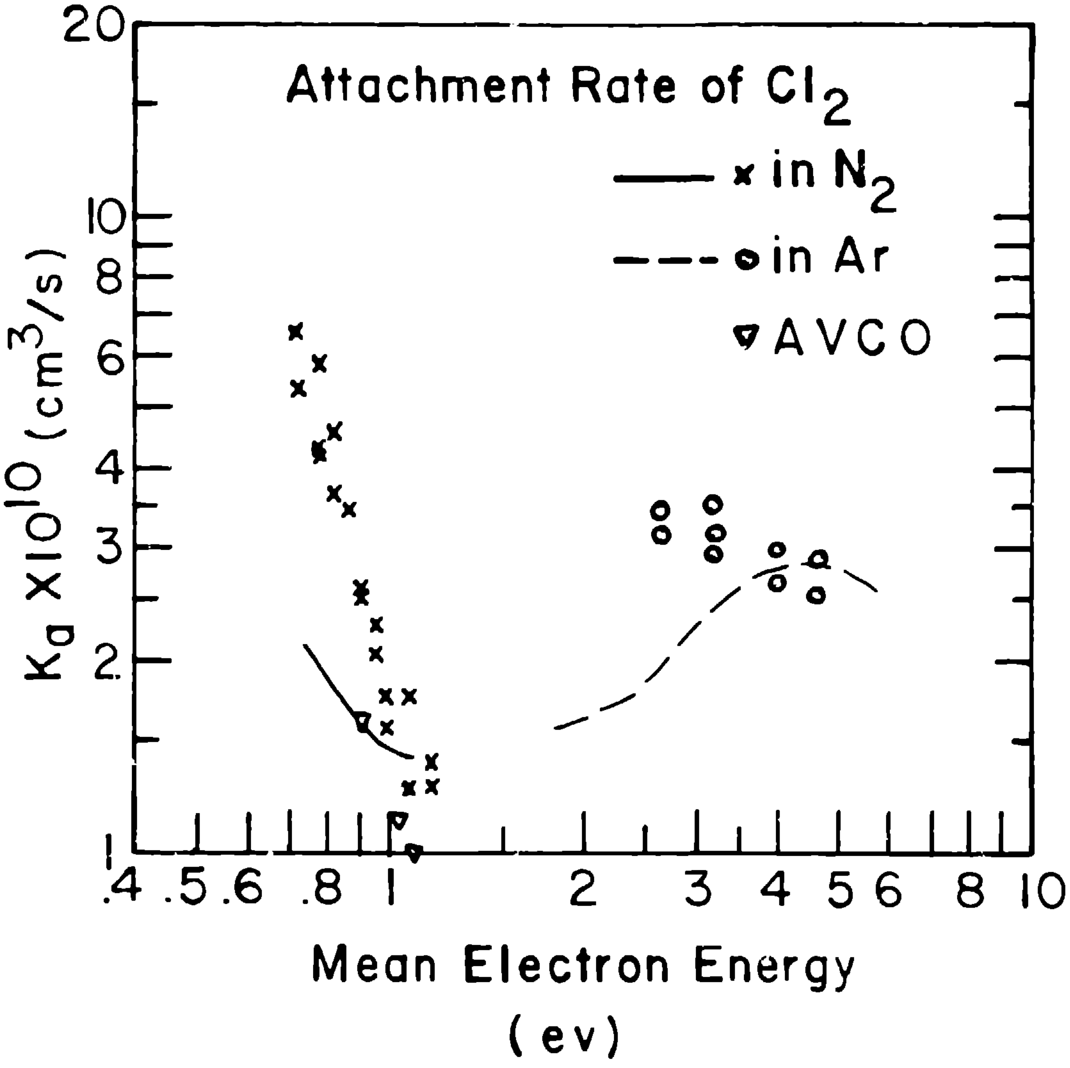
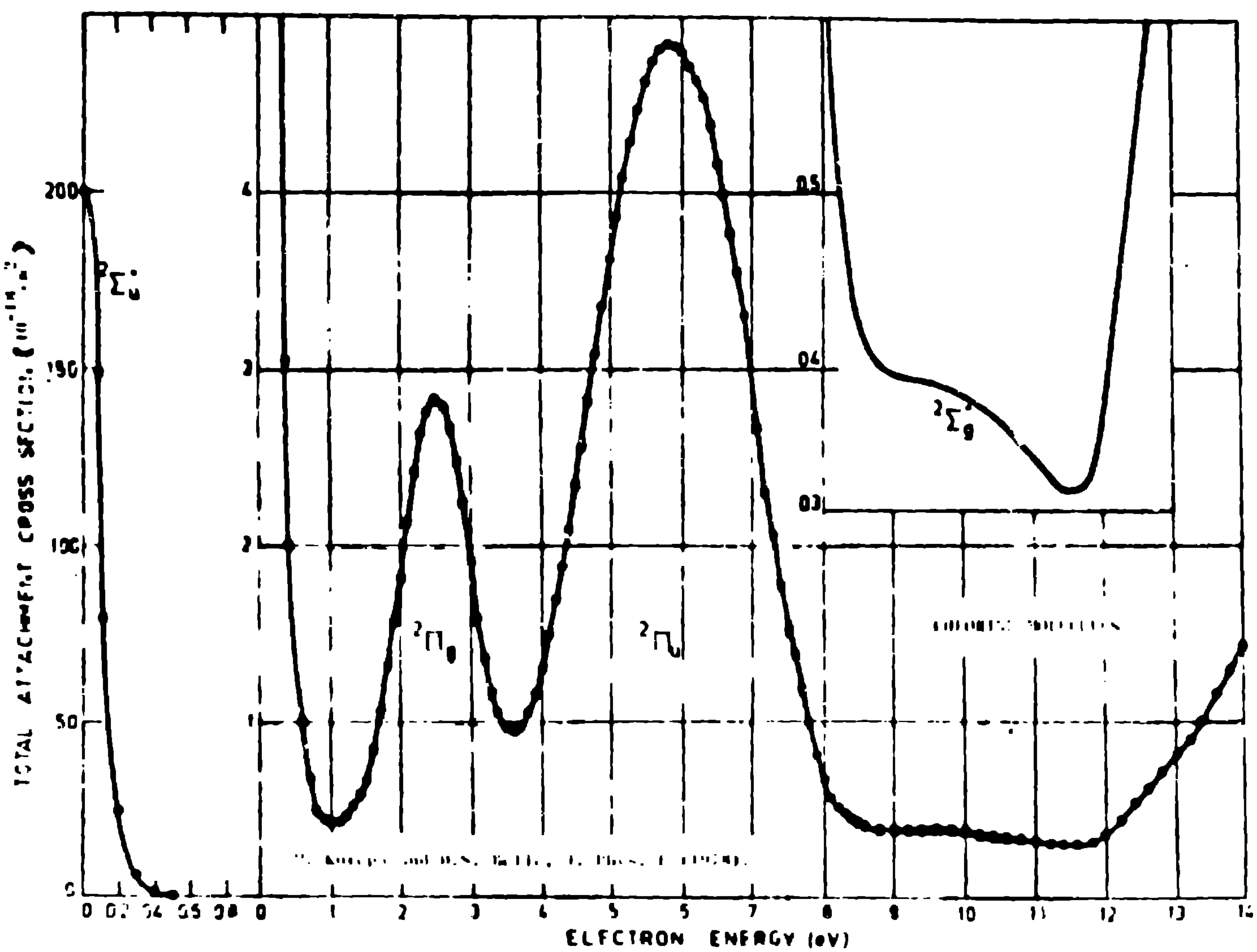
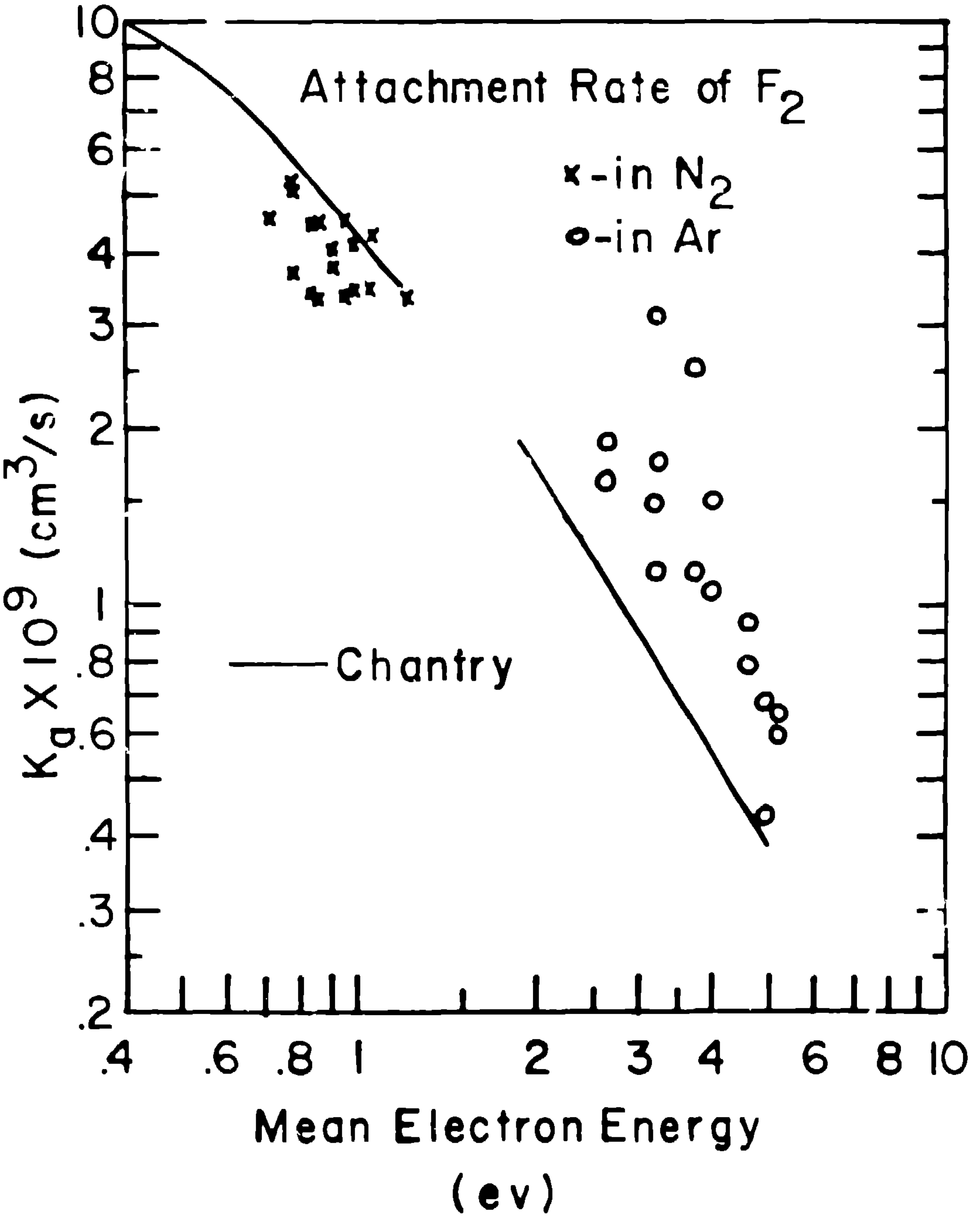

Attachment Rate of Cl_2
in N_2
in Ar
AVCO
$K_a \times 10^{10}$ (cm^3/s)
20
10
8
6
4
3
2
1
.4 .5 .6 .8 1 2 3 4 5 6 8 10
Mean Electron Energy
(ev)

Figure 6



TOTAL ATTACHMENT CROSS SECTION
ELECTRON ENERGY (eV)
0
50
100
150
200
1
2
3
4
0.3
0.4
0.5
0.2
0.4
0.6
0.8
5
6
7
8
9
10
11
12
13
14
$^2\Sigma_u^+$
$^2\Pi_g$
$^2\Pi_u$
$^2\Sigma_g^+$

Figure ?



Attachment Rate of F_2
x -in N_2
o -in Ar
Chantry
$K_a \times 10^9$ (cm^3/s)
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.4
.6
.8
1
2
3
4
6
8
10
Mean Electron Energy
(ev)

Figure 8